# Global Roadmap for Quantum Computation

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Since 2002, the Advanced Research Development Activity (ARDA)—the R&D funding coordinator for the Intelligence Community—has funded Richard Hughes from Los Alamos National Laboratory's Biological and Quantum Physics group (Chair) and Gary Doolen (Deputy Chair) to create and make available on the web an annual roadmap for quantum computation (QC). This roadmap has been formulated and written by the members of a Technology Experts Panel (TEP), whose membership consists of 20 internationally recognized researchers in quantum information science and technology. The current roadmap (version 2.0) and a list of panel members is at the website, qist.lanl.gov. (This summary consists mainly of excerpts from this 268-page document.)

The TEP members decided that the overall purpose of the roadmap should be to develop by 2012 a suite of viable emerging-QC technologies of sufficient complexity to function as a quantum computer. The intent of the roadmap is to set a path leading to the desired QC test-bed era by 2012 by providing some direction for the field with specific 5- and 10-year technical goals. While remaining within the "basic science" regime, the 5-year (2007) goal would project QC far enough in terms of the precision of elementary quantum operations and correction of quantum errors that the potential for further scalability could be reliably assessed. The 10-year (2012) goal would extend QC into the "architectural/algorithmic" regime, involving a quantum system of such complexity that it is beyond the capability of classical computers to simulate. These high-level goals are ambitious but attainable as a collective effort with cooperative interactions between different experimental approaches and theory. The TEP members emphasize that although these are desired outcomes, not predictions, they believe that they are attainable if the momentum in this field is maintained with focus on these objectives.

The roadmap summarizes the status and progress in each of the seven experimental approaches: NMR, Trapped Ion, Neutral Atom, Cavity QED, Optical, Solid State, and Superconducting. It also provides a 60-page summary of the theoretical aspects of QC and quantum information theory, as well as an extensive list of references and definitions of acronyms.

Table 1 has proven especially useful in summarizing the current state of progress towards a working quantum computer. The reader can quickly see which challenges remain to be overcome and which experimental approach has overcome the most challenges. A similar instructive table in the roadmap summarizes experimental progress toward a working quantum computer for these 7 experimental approaches on 28 detailed technical measures.

**Table 1.**
**The Mid-Level Quantum Computation Roadmap: Promise Criteria**

| QC Approach | The DiVincenzo Criteria: Quantum Computation #1 | #2 | #3 | #4 | #5 | QC Networkability #6 | #7 |
|---|---|---|---|---|---|---|---|
| **NMR** | 🔴 | 🟡 | 🟡 | 🟢 | 🟡 | 🔴 | 🔴 |
| **Trapped Ion** | 🟡 | 🟢 | 🟡 | 🟢 | 🟢 | 🟡 | 🟡 |
| **Neutral Atom** | 🟡 | 🟢 | 🟡 | 🟡 | 🟡 | 🟡 | 🟡 |
| **Cavity QED** | 🟡 | 🟢 | 🟡 | 🟡 | 🟢 | 🟡 | 🟡 |
| **Optical** | 🟡 | 🟡 | 🟢 | 🟡 | 🟡 | 🟡 | 🟢 |
| **Solid State** | 🟡 | 🟡 | 🟡 | 🟡 | 🟡 | 🔴 | 🔴 |
| **Superconducting** | 🟡 | 🟢 | 🟡 | 🟡 | 🟡 | 🔴 | 🔴 |
| **Unique Qubits** | This field is so diverse that it is not feasible to label the criteria with "Promise" symbols. | | | | | | |

Legend
- 🟢 = a potentially viable approach has achieved sufficient proof of principle
- 🟡 = a potentially viable approach has been proposed, but there has not been sufficient proof of principle
- 🔴 = no viable approach is known

The column numbers correspond to the following QC criteria:

#1. A scalable physical system with well-characterized qubits.
#2. The ability to initialize the state of the qubits to a simple fiducial state.
#3. Long (relative) decoherence times, much longer than the gate-operation time.
#4. A universal set of quantum gates.
#5. A qubit-specific measurement capability.
#6. The ability to interconvert stationary and flying qubits.
#7. The ability to faithfully transmit flying qubits between specified locations.